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Feasibility Tests for 400m Offset Zeroing the 25mm Gun of the Bradley Fighting Vehicle

12. PERSONAL AUTHOR(S) Perkins, Mike S.; and Wilkinson, Craig S. (Litton Computer Services Div., Litton Systems, Inc.)

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With the experimental procedure and target, gunners detected holes in the target and were able to perform accurate sight alignment following boresighting with either accurate or inaccurate equipment. Location of shot-group centers on a 1,000m target indicated that the gun was zeroed. Short-range zeroing has potential benefits in both training and combat when conditions are not optimal for standard zeroing.

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Mike S. Perkins and Craig S. Wilkinson
Litton Computer Services Division
Litton Systems, Inc.

for

Contracting Officer's Representative
Seward Smith

Field Unit at Fort Benning, Georgia
Seward Smith, Chief

Training Research Laboratory
Jack H. Hiller, Director

July 1988

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United States Army
Research Institute for the Behavioral and Social Sciences

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U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON **Technical Director**	**JON W. BLADES** **COL, IN** **Commanding**

Research accomplished under contract
for the Department of the Army

Litton Computer Services Division
Litton Systems, Inc.

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FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) has contributed to a program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with that program, this research developed and tested a short-range zeroing procedure and target for the 25mm gun to minimize the negative impact of factors (e.g., inaccurate boresight equipment, ammunition dispersion, poor feedback of hit location) that affect zeroing conducted with standard procedures.

ARI's Fort Benning Field Unit, a division of the Training Research Laboratory, monitored this research. ARI's mission is to conduct research of training and training technology using infantry combat systems and problems as mediums. The research task that supports this mission, "Advanced Methods and Systems for Fighting Vehicle Training," is organized under the "Train the Force" program area. Sponsorship for this research is provided by a Memorandum of Understanding (effective 31 May 1983) between the U.S. Army Infantry School (USAIS), Training and Doctrine Command (TRADOC), Training Technology Agency, and ARI, which established how joint efforts to improve BFV tactical doctrine, unit, and gunnery training would proceed.

FEASIBILITY TESTS FOR 400M OFFSET ZEROING THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

EXECUTIVE SUMMARY

Requirement:

Observations of zeroing the 25mm gun of the Bradley Fighting Vehicle (BFV) suggested that the accuracy of sight alignment was decreased by inaccurate boresight equipment, excessive ammunition dispersion, and difficulties determining round-impact location. In an effort to minimize the impact of these factors, a special short-range zeroing target and procedure were developed and tested.

Procedure:

The 400m offset zeroing target was an 8-foot square with a dark-green background and light-colored aiming points and reference circles. The aiming points for the integrated sight unit (ISU) gun reticle and gun bore were offset a distance that allowed gun and sight aiming points to converge at a range of 1000 to 1200 m. The zeroing procedure used the center of a three-round shot group for training ammunition to align the sight.

Students receiving BFV gunnery training at Fort Benning were used to test the target and procedure. Prior to zeroing, one group of students (Experiment 1) boresighted with issued equipment while another group (Experiment 2) was given equipment that was screened for accuracy. The first shot group was fired at the 400m target and the reticle was aligned to the shot-group center. A second shot group was fired to determine the zeroing accuracy obtained as a result of the first sight alignment. A third shot group was fired at a 1000m target to determine the effectiveness of the 400m offset zeroing procedures.

Findings:

Holes in the target were visible with the ISU, allowing BFV crews to determine round-impact location during zeroing. The first shot-group center after boresighting was much more accurate after boresighting with screened equipment (average of 1 mil from target center) than with issued equipment (2.7 mils). After sight alignment, the center of the second shot group as usually 0.5 to 1.0 mils from target center when either screened or unscreened boresight equipment was used. Location of shot-group centers on the 1000m target indicated that the gun was zeroed.

Utilization of Findings:

The 400m offset zeroing procedure permits accurate sighting alignment because holes in the target are visible and the target is easy to hit even with inaccurate boresighting. Short-range offset zeroing has potential benefits in both training and combat when conditions are not optimal for standard zeroing.

FEASIBILITY TESTS FOR 400M OFFSET ZEROING THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

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FEASIBILITY TESTS FOR 400M OFFSET ZEROING THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

INTRODUCTION

Background

Since August 1983, the Fort Benning Field Unit of the Army Research Institute (ARI) and its resident contractor, Litton Computer Systems, has conducted research to improve operational effectiveness of the Bradley Fighting Vehicle (BFV) under all visibility conditions. As summarized in separate reports (Perkins, 1987 & Perkins, 1988b), a major emphasis was to develop techniques and procedures to improve the first-round accuracy with the 25-mm automatic gun.

At a minimum, first-round hits with the 25-mm gun require accurate alignment between the sight and gun. Boresighting aligns the sight with the aiming point of the gun bore at the range of the boresighting target. Boresighting should be followed by zeroing to refine sighting accuracy. During zeroing, the sight is aligned with round-impact location. Small sighting adjustments may be made during zeroing because the aiming point of the gun bore achieved during boresighting may not indicate the location of round impact.

As described in the version of the BFV Gunnery field manual in effect at the onset of these experiments (FM 23-1, 1983), zeroing is conducted on a 4-foot square, white panel at 1200 meters. The armor-piercing (AP) round is the preferred ammunition for zeroing because it is more accurate (i.e., has low levels of dispersion) than high-explosive (HE) and training practice (TP-T) ammunition. A round is fired, and if a hit is observed in the 1-mil circle of the integrated sight unit (ISU) gun reticle, the weapon is zeroed. If the criterion is not met, a second and third round are fired with a check for accuracy after each round. If the weapon is not zeroed within three rounds, boresighting is repeated using a different boresight kit. A maximum of three more rounds is fired with a check of accuracy after each round. Organizational maintenance is notified if the weapon cannot be zeroed. If either HE or TP-T is the only ammunition available, zeroing is conducted as described for AP ammunition.

Observations of gunnery training during institutional training at Fort Benning indicated a number of problems associated with the conduct and the accuracy of zeroing with TP-T ammunition (Perkins, 1987). Problems relevant to the current research include:

- Zeroing was conducted on targets other than the boresighting\zeroing target,
- Rounds usually missed the zeroing targets by substantial margins after boresighting,
- Sighting adjustments often failed either to product improvements in accuracy or to meet accuracy standards,
- The number of rounds used to zero usually exceeded the allotment specified in the BFV Gunnery field manual (FM 23-1, 1983).

In contrast to use of the recommended white boresighting panel, zeroing at Fort Benning is usually conducted on dark green, frontal silhouettes of a BMP. Use of a dark-colored target provides a good contrast to observe the location of round-impact. The bright 25-mm tracer is difficult to spot against the white background of the boresighting/zeroing target recommended in the gunnery manual (FM 23-1, 1983).

Previous research suggests that target misses after boresighting are a result of inaccurate boresight equipment (Perkins and Wilkinson, 1988). First round misses may then make it difficult to perform accurate sighting adjustments. When the round flies over or to the side of the target, gunners have difficulty determining where the round passes the plane of the target.

Determining round-impact location is one of the biggest problems in zeroing. Accurate zeroing requires knowledge of round-impact location which is very difficult if the projectile misses the target. Moreover, it is not always easy even when the round hits the target because a hole cannot be seen at the recommended zeroing range of 1200 m (FM 23-1, 1983).

Projectile dispersion can adversely affect zeroing accuracy. As dispersion increases, a single round may fail to provide an accurate estimate of true center-of-impact for the weapon system. When training ammunition has maximum allowed dispersion, a previously conducted mathematical analysis predicted that 90% of the rounds may fall up to 2 mils from target center. Use of a sight alignment procedure based on the center of a three-round shot group for TP-T ammunition is predicted to produce a 50% increase in sighting accuracy over the single-round based procedure (Perkins, 1988a).

In summary, given the low target hit probability following boresighting, problems associated with determining round-impact location for target misses, and the inaccuracy associated with the single-round based sight adjustment procedure, it is not surprising that zeroing often requires more rounds than specified.

Objectives

The overall objective was to develop a zeroing procedure that would allow accurate zeroing with TP-T ammunition. Specific objectives were to:

- Increase likelihood of hitting the zeroing target after boresighting,
- Improve the gunner's capability to estimate round-impact location,
- Improve the accuracy of sight alignment.

Attempts to meet the preceding objectives were achieved by the following equipment and procedural modifications:

- Use of a zeroing target with a dark background to allow the gunner to determine where the round penetrates the target,

- Position the zeroing target at 400 m to allow the gunner (a) to see holes in the target and (b) to increase the probability of target hits after boresighting,

- Use the center of three-round shot groups to improve the accuracy of sight alignment,

- Use a score sheet to plot rounds and to determine the shot-group center for sight alignment purposes.

Using a short-range target (400 m) should increase the liklihood of a first-round hit. However, to insure that the ISU reticle and gun are aligned at 1200 m, it was necessary to use different aiming points on the target for the gun reticle and the gun bore. The relative position of these two aiming points was based on (a) parallax between the sight and the gun bore and (b) drift of the projectile. Properly positioned aiming points on the 400-m offset zeroing target should produce an alignment between the sight and gun that is equivalent to standard zeroing procedures conducted at 1200 m.

The center of three-round shot groups was used to increase the accuracy of the sight alignment when zeroing with TP-T ammunition. Based on maximum allowed ammunition dispersion, the calculations from a previous analysis (Perkins, 1988a) indicated that the center of the shot group should fall within a 1 mil radius of the target center following sight alignment.

EXPERIMENT 1

An initial feasibility test was conducted to determine if a 400-m offset zeroing target used with sighting adjustments based of the center of three-round shot groups could be used to zero the 25-mm gun with TP-T ammunition.

Method

Subjects

The experimental zeroing procedure was conducted by 12 turret crews (commander and gunner) from Class 3-85 of the BFV Commander Course.

Equipment

The 400-m offset zeroing target. The 400-m offset zeroing target used during Experiment 1 is illustrated in Figure 1. The 8-foot square target was constructed from two pieces of 4-feet by 8-feet plywood that were 3/8-inch thick. The background was painted dark green. A 4-inch white dot in the center of the target was the aiming point for the gun bore during boresighting; rounds should impact around the center dot for a perfectly zeroed weapon. The 2-mil and 4-mil white circles were 16 and 32 inches in diameter, respectively, painted with 2-inch wide lines. The circles were used as both references and measurement aids to estimate and plot round-impact location on score sheets.

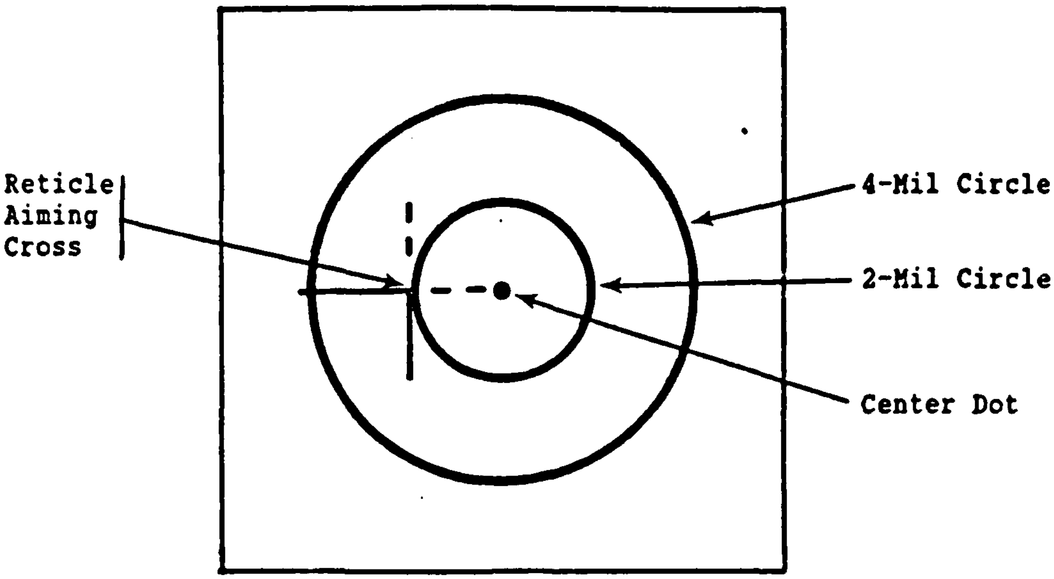


Figure 1. Illustration of the 400m offset zeroing target used during Experiment 1.

During boresighting and zeroing, the gun reticle was aligned and aimed, respectively, with the reticle aiming cross. The cross was offset 16 inches to the left of the center dot. This lateral displacement adjusts for the horizontal (i.e., azimuth) parallax between the gun reticle and gun bore so that zeroing performed at 400 m would produce nearly the same effect as the standard 1200 m procedure. Mathematical calculations indicated that perfect sight to gun alignment would be produced with about a 13.5 inch offset. However, 16 inches was chosen so that all target dimensions could be produced with a single measurement or multiple of it (e.g., the 4 mil circle). This would facilitate construction of a field-expedient zeroing target as will be discussed in the Summary and Conclusion section.

The reticle aiming cross was yellow and one-inch wide. Each arm of the cross was 16-inches long (1 mil at 400 m). When viewed through the ISU, the aiming cross had a color and line width similar to that of the gun reticle. The reticle aiming cross was only faintly visible when viewed with the unaided eye from the firing line.

The selection of 400 m for zeroing was partly determined by availability of targets on firing ranges. The target for this experiment was placed over a permanently emplaced 400-m target that is used for zeroing the coaxial machine gun at Ware Range. A range of 400 m can also be indexed into the fire-control system.

The score sheet. A special zeroing score sheet (see Figure 2) was designed to collect data on zeroing and to allow accurate zeroing by the crew (see Figure 2). The score sheet had scaled drawings of the 400-m offset zeroing target to allow the crew to plot round-impact location and to determine shot-group centers for purposes of performing sight alignment.

Vehicles. Testing was conducted using BFVs provided in support of the BFV Commander Course.

Procedure

Conduct of testing over a four-day period both (a) minimized interference with training objectives (b) and supported the training mission. All vehicles that were used for live-fire training were zeroed using the experimental procedure. As a result of testing, weapons (the 25-mm gun and 7.62-mm coaxial machine gun) were zeroed prior to scheduled live-fire training exercises.

Boresighting. Boresighting of the 25-mm gun was performed as recommended in the turret technical manual (TM 9-2350-252-10-2, 1984) with the following exceptions. The boresight telescope was aimed at the center dot of the target and the ISU-day reticle was adjusted to the aiming cross of the target. The coaxial machine gun was boresighted with both the boresight telescope reticle and ISU-day reticle positioned on the center dot of the target.

Zeroing. Two vehicles were on the firing line at one time. One vehicle prepared for zeroing while the other zeroed. Prior to testing, an experimenter presented a 10-minute orientation to each crew on the purpose and procedures of the test. During testing, the crew was in the turret while an experimenter and an instructor were seated on opened turret hatches. The crew was allowed to use a step-by-step job performance aid (see Appendix A) to conduct the zeroing procedure. However, both the instructor and experimenter insured that the zeroing procedure was correctly followed. Either the instructor or experimenter used 7-power binoculars for observing fire.

Zeroing was performed with a range control setting of 400 m. The ISU magnification was set on high, reticle brightness was adjusted to a low level to minimize sight-picture "clutter," and the rate of fire was set on the single-shot mode. The procedure was divided into three phases.

I. Fire a three-round shot group at the 400-m offset zeroing target and align the sight to the shot-group center.

II. After re-aiming at the 400-m offset zeroing target, fire a second shot group and align the sight to the shot-group center.

III. After aiming at a standard 1000-m boresighting/zeroing target, fire a shot group and align the sight to the shot-group center if necessary.

For the first three rounds fired after boresighting, round-impact location was recorded on a score sheet and the center of the shot group was determined. Because the aiming points of the target for the ISU reticle and gun bore were offset, the reticle was adjusted 1 mil to the left of the shot group center. This distance was estimated on the score sheet using the distance between the center dot and the edge of 2-mil circle.

During the second phase, a second three-round shot group was fired at the 4CC-m target to estimate zeroing accuracy following the initial sight alignment (Phase I). After the shot-group center was determined, the ISU reticle was adjusted with the boresight knobs if the center was located more than 0.5 mils from the center dot of the target.

Phase III of zeroing determined if the 400-m offset zeroing procedure produced a weapon that was zeroed at the recommended range (1200 m). The only target near that range in the lane (Firing Point 1 on Ware Range) used for testing was a 1000-m white boresight panel. Calculations based on both horizontal aspects of gun-sight parallax and projectile drift indicated that zeroing is nearly identical at 1000 and 1200 m (Perkins, 1986b) so the 1000-m target was used in Experiment 1.

During Phase III, the turret and gun controls were used to aim center-of-mass on a 1000-m target. Three rounds were fired, round-impact location was plotted on the score sheet, and the shot-group center was estimated and plotted. The weapon was considered zeroed if the shot-group center was on the target.

Data. The primary data was obtained from zeroing score sheets. The gunner usually recorded round-impact location but both crew members usually concurred on the plotted location of impact. The experimenter and instructor inspected the plotting of each round. Students had higher magnification (12 power on the ISU vs. 7 power for binoculars) and less parallax to observe impact location so their observations were considered more valid than those of the experimenter and instructor. In most cases, students reported that a hole could be seen at the point of penetration on the target.

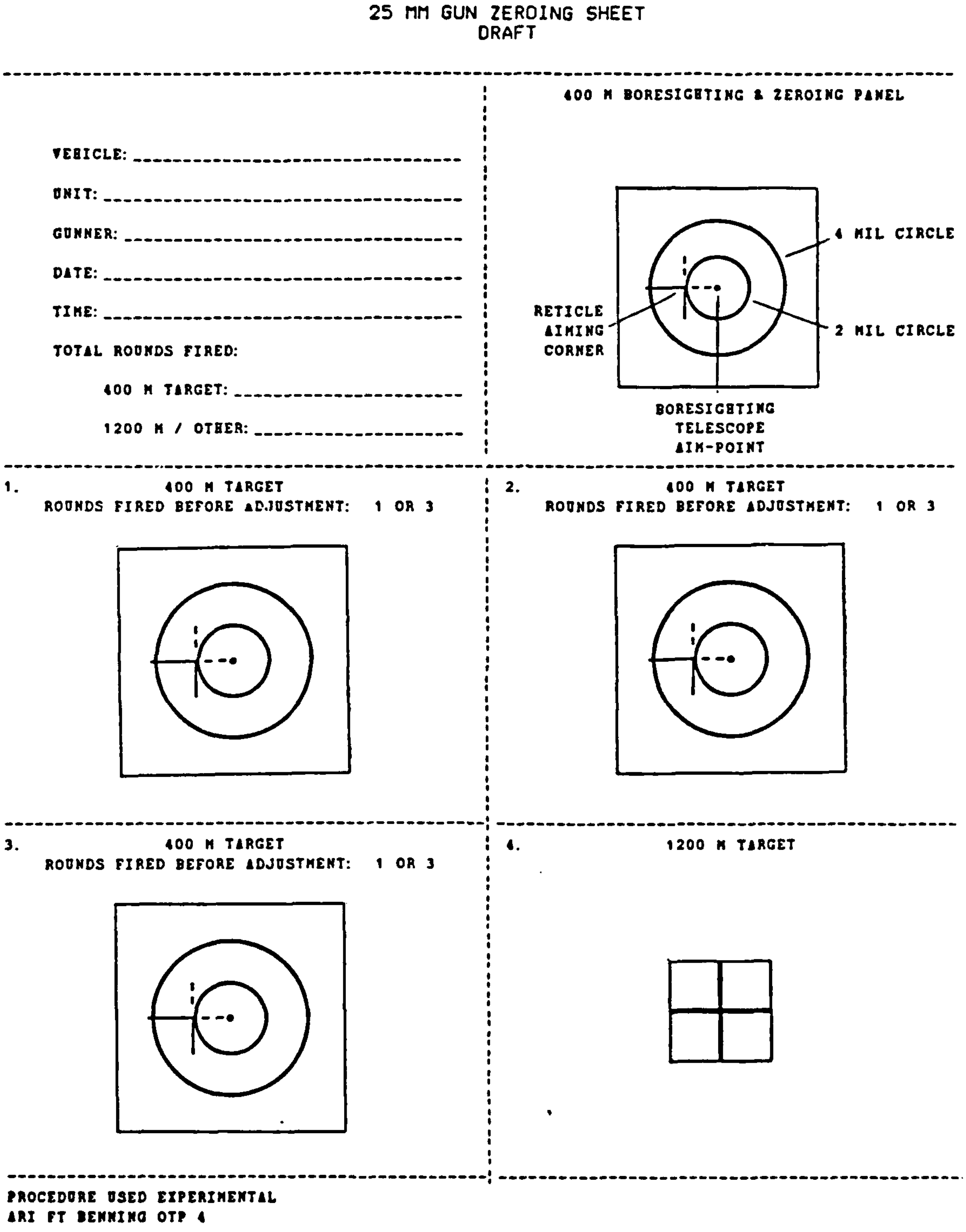
Students marked the center of a shot group on the score sheet and the instructor and experimenter confirmed the estimation. The experimenter then marked a reticle adjustment cross on the sheet. This cross was used by the student to align the gun reticle using the day boresight knobs.

After completion of testing, the score sheets were used to estimate x-coordinates (azimuth) and y-coordinates (elevation) for round-impact locations and shot-group centers. The center dot of the target was assigned the value of $x = 0$ and $y = 0$. The distance of round-impact location from target center was determined using a gridded, transparent overlay that was placed over the target on the score sheet. Round-impact location data was then converted to both inches and mils for analysis. The x- and y-coordinates for each impact location and the shot-group center was used to determine the distance in mils of each impact location from the center dot of the target.

Results

Data from 3 of 12 crews were not analyzed for the following reasons. One vehicle accidently turned on turret stabilization and drift had not been eliminated before zeroing. Another vehicle had gun reticle movement during firing because of a poor resolver. Data from a third crew was considered invalid because gun reticle adjustments may not have been performed correctly, and there was a dispute between students, the instructor, and an observer concerning round-impact location on the 1000-m confirmation target.

Figure 3 presents the location of shot-group centers for crews that correctly performed the zeroing procedure. Data was plotted on a drawing with 2- and 4-mil circles surrounding a cross with lines representing 1-mil lengths from the center dot.



25 MM GUN ZEROING SHEET
DRAFT

VEHICLE: ______________________________
UNIT: ______________________________
GUNNER: ______________________________
DATE: ______________________________
TIME: ______________________________
TOTAL ROUNDS FIRED:
400 M TARGET: ____________________
1200 M / OTHER: ____________________

400 M BORESIGHTING & ZEROING PANEL

4 MIL CIRCLE
RETICLE AIMING CORNER
2 MIL CIRCLE
BORESIGHTING TELESCOPE AIM-POINT

1. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

2. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

3. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

4. 1200 M TARGET

PROCEDURE USED EXPERIMENTAL
ARI FT BENNING OTP 4

Figure 2. A sample zeroing score sheet used during Experiment 1.

Section A of Figure 3 represents shot-group centers fired after boresighting. The average shot-group center was 2.6 mils from target center. One crew missed the target (note shot-group center located to the left and up from the target). Inaccurate boresight equipment may have accounted for target misses because the boresight reticle moved off the target following 90-degree rotation of the telescope. This boresight equipment was used on other occasions during testing. One crew asked the instructor if they should get another kit but were told that they probably would not get a noticeably better one.

As shown in Section B of Figure 3, sight alignment after the first shot group resulted in a second shot-group center that was much closer to target center. Data from only eight crews were analyzed because one crew inaccurately performed reticle alignment. Shot-group centers averaged about 0.7 mils from target center. Only one of the shot groups was located more than 1 mil from target center, and interestingly, this was from the vehicle that missed the target after boresighting. When the overall group mean was based only on the seven vehicles that hit the target after boresighting, the average shot-group center was 0.5 mils from target center.

Analysis of shot-group center location on the 1000-m target was based on seven vehicles. One set of data could not be used because of incorrectly performed sight alignment while another had insufficient time to zero. Five of seven shot-group centers were on the target and two were located above the target. On the average, shot-group centers missed the target center by 1.0 mil. Shot-group centers were usually above center-of-mass. The average location of all shot group centers was about 12 inches to the left and 28 inches up from target center.

As a general note, holes in the 400-m target could be seen using the ISU. Estimating round impact was reported by students to be relatively easy during days 1 and 2 of testing, but by the last day, it became much more difficult as the number of holes increased. Students could see where the round entered the target, but presence of a large number of holes made it difficult to determine the exact location of the fired round.

Discussion

The sizeable distance between the first shot-group centers and target center after boresighting was probably caused by inaccurate boresight equipment. Analysis of boresight equipment accuracy after the conduct of Experiment 1 determined that the typical kit at Fort Benning produced a sighting error of 1.4 mils. Furthermore, it was not uncommon to find errors greater than 2 or 3 mils (Perkins and Wilkinson, 1988) and a kit with that level of error was used during Experiment 1.

Relatively small boresighting errors can lead to target misses during zeroing. For example, at the recommended zeroing range of 1200 m, an 8-foot square boresighting/zeroing target (the size of targets on firing ranges at Fort Benning) is only about 2 mils high and wide. With a center-of-mass aiming point, only a 1-mil error in the trajectory of the projectile will cause a target miss. In Experiment 1, shot-group centers averaged 2.6 mils

A. AFTER BORESIGHTING

B. AFTER THE FIRST RETICLE ALIGNMENT

C. 1000-M CONFIRMATION

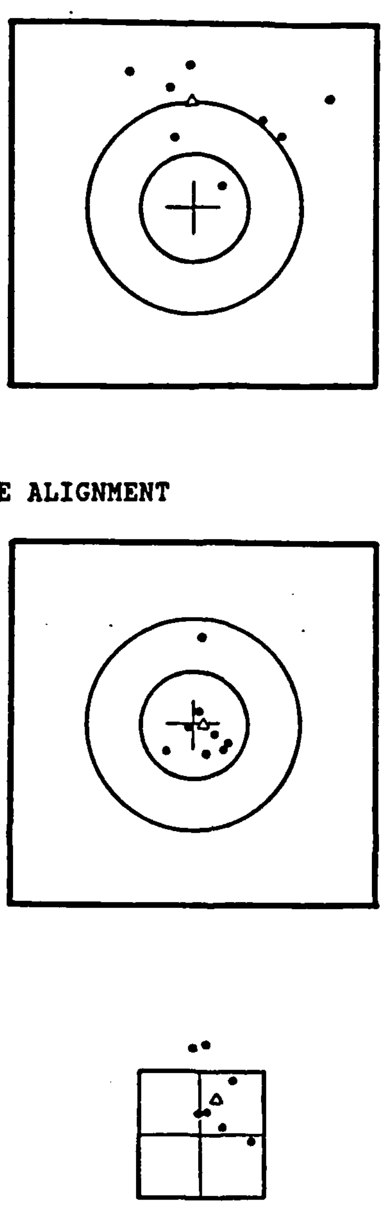


Figure 3. Three-round shot group centers for each vehicle: A. after boresighting (first shot group on 400-m target), B. after the first reticle alignment (second shot group on 400-m target), and C. 1000-m confirmation. The triangles represent the location of impact based on the average of all shot groups.

from target center. This margin of error suggests that target misses would have occurred using the recommended zeroing procedure with targets at Fort Benning (8-foot square targets at 1200 meters). Using the data from Experiment 1, it was predicted that only one vehicle would have hit a standard boresighting/zeroing panel at 1200 m after boresighting.

Data indicate that a zeroing criterion of 1 mil from target center can be achieved. Eight of nine crews had their second shot-group center in the 2-mil circle of the target. The only crew that missed the 2-mil circle on the second shot group, missed the target on the first shot group. Given the hypothesis that it is difficult to determine round location during target misses, it is likely that this crew failed to meet the 1-mil criterion because they received poor feedback (i.e., rounds missed the target and produced no holes) on the location of the first shot group.

Based on round-impact location on the 1000 m target, data suggest that the 400-m offset zeroing procedure produced more effective zeroing in the horizontal than the vertical direction (i.e., rounds tended to be higher than they were wide). After completion of Experiment 1, a design flaw in the 400-m offset zeroing target was detected. The location of the reticle aiming cross relative to the center dot failed to account for vertical parallax between the sight and gun. As a result of the design flaw, the sight and gun were aligned in the vertical dimension at 400 m but the line of sight was below the aim of the gun at 1000 meters.

EXPERIMENT 2

Experiment 1 indicated that certain modifications would enhance the effectiveness of the 400-m offset zeroing procedure. The modifications and their rationale are as follows:

- Use of accuracy boresight equipment to improve accuracy of the first-shot group,
- Reposition the reticle aiming cross on the 400-m target to account for vertical parallax between the sight and gun,
- Patching of holes on the 400-m offset zeroing target at the end of a day's firing in attempt to improve detection of round-impact location.

Experiment 2 attempted to shorten the distance between center-of-impact and target center for rounds fired after boresighting. As a result of previous testing of boresight equipment, it was possible to identify accurate boresight telescopes and 25-mm adapters (Perkins and Wilkinson, 1988). This accurate equipment was used during Experiment 2.

In Experiment 1, the location of the second shot group was clustered very near the center of the 400-m target. However, shot groups tended to be high on the 1000 m confirmation. Failure to account for vertical parallax between the sight and gun was the likely cause of this and was corrected in Experiment 2.

Method

Testing was conducted using six student crews from Class 3-85 of the BFV Gunner Course. The 400-m offset zeroing procedure substituted for the normal zeroing to be conducted for live-fire training. Four BFVs were on the firing line at Ruth Range. Two experimenters worked on separate vehicles so it was possible to zero one half of the vehicles used during three days of training. During zeroing, one student occupied the gunner's position and an instructor observed from the commanders position. The experimenter sat in an open hatch on top of the turret.

The boresighting kits used were the most accurate ones identified from previous research at Fort Benning (Perkins and Wilkinson, 1987). It is estimated that kits produced errors that ranged from 0.4 to 0.7 mils from the aiming point of the centerline of the gun bore.

The 400-m offset zeroing target was identical to Experiment 1 with the exception that the reticle aiming cross was elevated 12 inches. Holes in the target were patched on the morning after a day's firing; rubber patches were cut from pieces of swim-barrier repair kit. Patches were then glued on the front of the target. The color of the patch resembled that of the background color of the target.

A 1000-m dark green, frontal silhouette of a vehicular target was used for confirmation. This target range was selected because the standard boresighting panel in the firing lane used for testing was at a range of 1400 m. This distance was considered too long for accurate detection of round impact, particularly with a white target. Furthermore, the boresighting panel is positioned above the ground making it more difficult to accurately locate rounds that fly underneath the target.

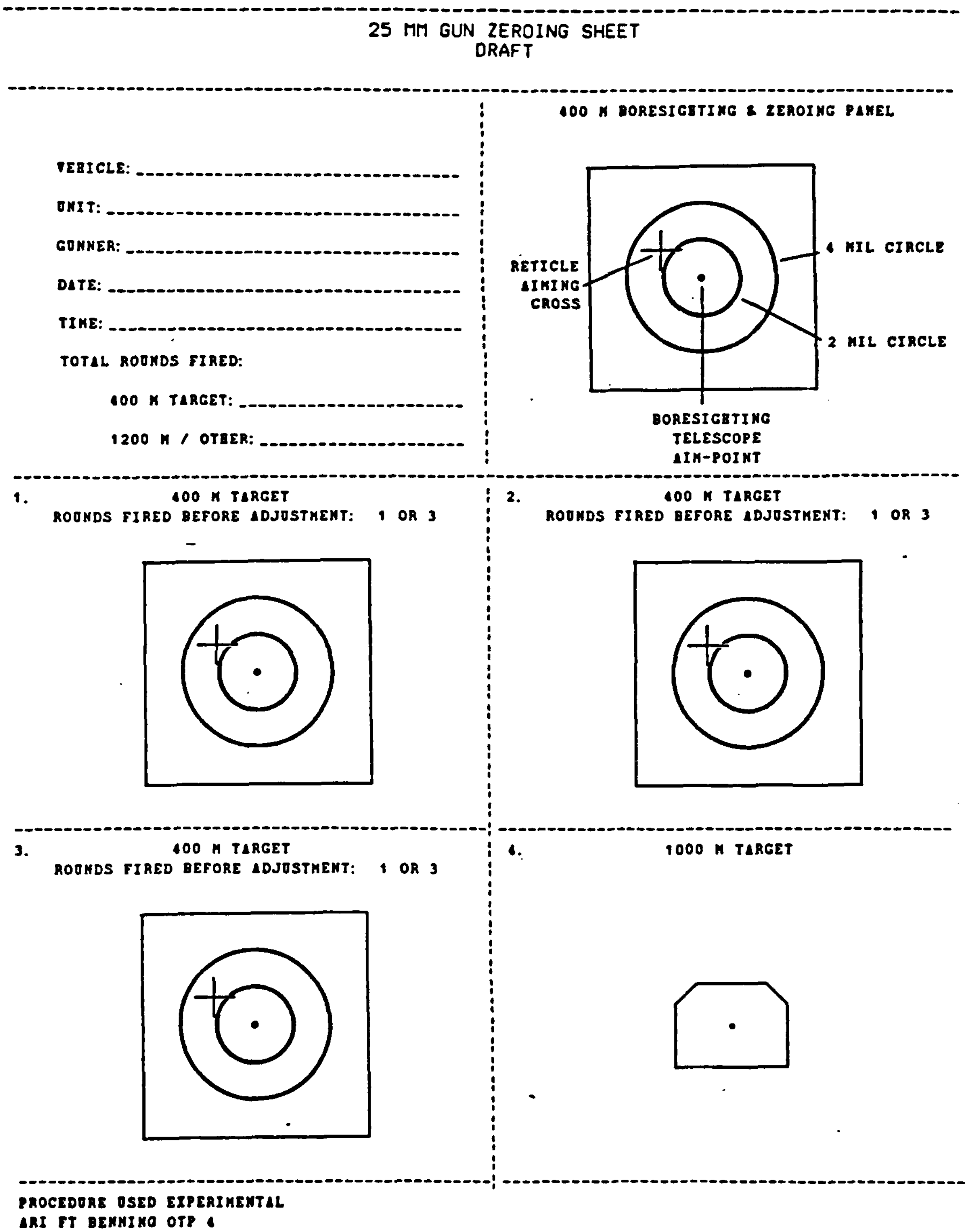
The zeroing score sheet was modified as shown in Figure 4. Changes from Experiment 1 included the repositioning of the reticle aiming cross and a scaled drawing of the 1000-m confirmation target. The step-by-step zeroing procedure is presented in Appendix B. In addition, an overlay illustrated in Figure 5 was used as a job performance aid to mark on the score sheet the location of reticle alignment after determining the center of a shot group.

Results

The location of shot-group centers after boresighting and after the first reticle alignment are illustrated in Figure 6. As shown in Section A of Figure 6, the first shot group from five of six vehicles was no more than 1 mil from the target center. The average distance from the target center was 1.05 mils.

After sight alignment based on the first shot group, all of the shot-group centers for the second shot group were located within 1 mil of the target center. The average distance from the center was 0.8 mils with only one of six shot-group centers being less than 0.5 mils from the target center.

The data for 1000-m confirmation firing, as illustrated in Figure 7, was complicated by range operation problems. The first two vehicles, whose data


25 MM GUN ZEROING SHEET
DRAFT

VEHICLE: ______________________
UNIT: ______________________
GUNNER: ______________________
DATE: ______________________
TIME: ______________________
TOTAL ROUNDS FIRED:
400 M TARGET: ______________
1200 M / OTHER: ______________

400 M BORESIGHTING & ZEROING PANEL
RETICLE AIMING CROSS
4 MIL CIRCLE
2 MIL CIRCLE
BORESIGHTING TELESCOPE AIM-POINT

1. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

2. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

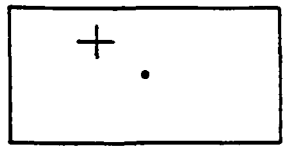
3. 400 M TARGET
ROUNDS FIRED BEFORE ADJUSTMENT: 1 OR 3

4. 1000 M TARGET

PROCEDURE USED EXPERIMENTAL
ARI FT BENNING OTP 4

Figure 4. A sample zeroing score sheet used during Experiment 2.

BORESIGHT RETICLE ADJUSTMENT OVERLAY



1. Align overlay with target on Zeroing Sheet.
2. Position dot of overlay on shot group center on Zeroing Sheet.
3. Mark through the center of Cross on overlay onto Zeroing Sheet to show the Reticle Adjustment Mark.

Figure 5. Overlay used to mark reticle alignment position.

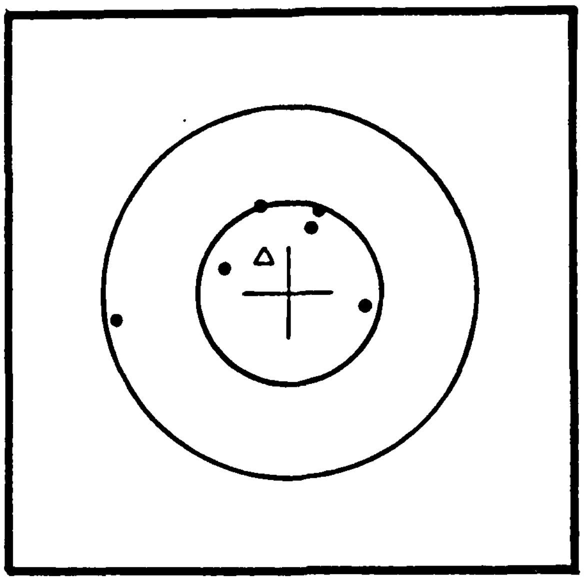
is illustrated by dots in Figure 7, were zeroed using the scheduled 1000-m target. After the first two vehicles were zeroed, the 1000-m target failed to operate and confirmation had to be conducted on a target with a range of 900 m. Shot-group centers for the four vehicles zeroed at 900 m are illustrated by open circles in Figure 7. Nine hundred meters cannot be indexed into the fire control system so a range control setting of 1000 m was used. The 25-mm firing table was then used to estimate round-impact location if a 900-m range control setting had been used. This adjusted data is represented in Section B of Figure 7. Note the average location of all six shot groups, as indicated by the triangle on the target, was very close to target center-of-mass.

As mentioned in the Method section, a 1000-m target was selected for zeroing confirmation as a 1200 m target was not available. However, one test vehicle fired at both 1000 and 1400 m targets with the appropriate range control settings. Projectiles impacted in and around the center of mass at both target ranges.

SUMMARY AND CONCLUSIONS

Two tests examined the feasibility of using a 400-m offset zeroing procedure and three-round shot groups to zero the 25-mm gun with TP-T ammunition. The accuracy of shot-group centers on the first shot group depended on the accuracy of boresight equipment used prior to zeroing. Shot-group centers were considerably further from target center when crews boresighted with issued equipment (mean of 2.6 mils from target center for Experiment 1) as compared to screened and accurate equipment provided by the experimenter (mean of 1.05 mils for Experiment 2). After the first sight alignment, the accuracy of the second shot-group center was nearly identical for vehicles that had been zeroed with unscreened and screened (accurate) boresight equipment. The center of the second shot-group was located within 1 mils of target center in 92% of the cases. When the optimal design for the 400-m offset zeroing target was used (Experiment 2), shot-groups were centered around center of mass on the confirmation target.

A. AFTER BORESIGHTING



B. AFTER FIRST RETICLE ALIGNMENT

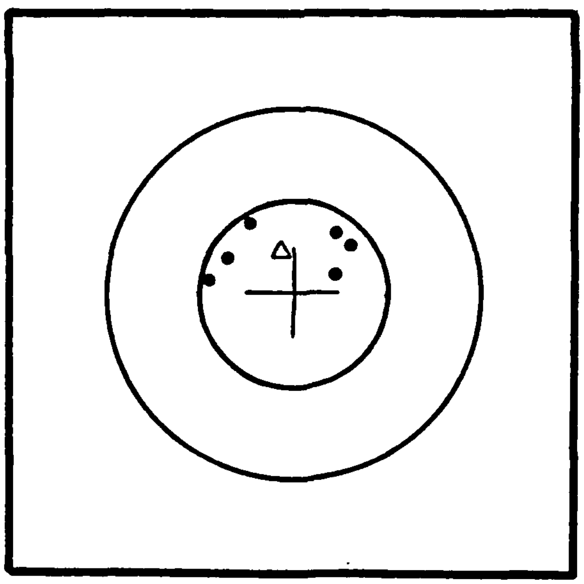
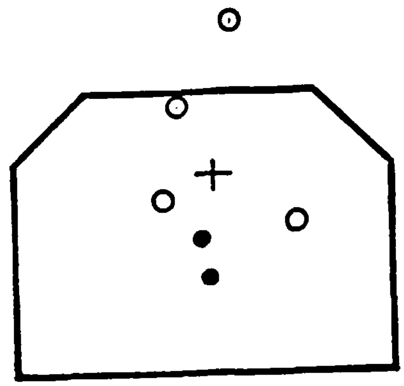


Figure 6. Shot-group centers (n = 6): A. after boresighting and B. after the first reticle alignment. The mean of all shot groups is illustrated by triangles.

A. ACTUAL LOCATION



B. ADJUSTED LOCATION

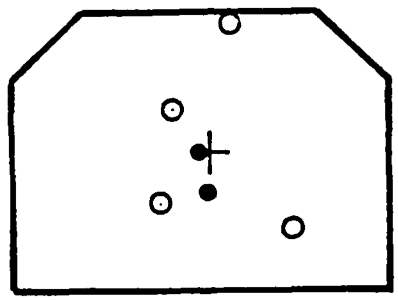


Figure 7. Shot-group centers during 1000-m confirmation: A. actual location and B. adjusted location. The adjustment was based on ballistics data to estimate round-impact location if 900 m could have been indexed into the fire-control system on the 900-m target.

Impact of Boresighting on Zeroing

The existence of inaccurate boresight equipment was a major reason for the development of the 400-m offset zeroing procedure. Inaccurate boresighting can lead to target misses during zeroing, and target misses make it difficult to achieve accurate sight alignment during zeroing. The large zeroing target (8-ft square) was used at short-range (400 m) in an effort to capture errant rounds fired as a result of inaccurate boresighting.

The 400-m zeroing target allowed target hits even with inaccurate boresight equipment (89% of shot group centers were on target in Experiment 1). Further predictions suggest that target hits would not have occurred on a standard boresighting\zeroing target positioned at the recommended range of 1200 m. The shaded squares in Figure 8 indicate the visual size (in mils) of an 8-foot square zeroing target at 1200 m. A shot-group center located in the shaded square predicts that the shot-group center would have been located on a zeroing target at 1200 meters. Predictions indicate that use of unscreened boresight equipment (Experiment 1) would have resulted in only 11% of shot-group centers on target in contrast to 83% of shot group centers on target following use of accurate boresight equipment.

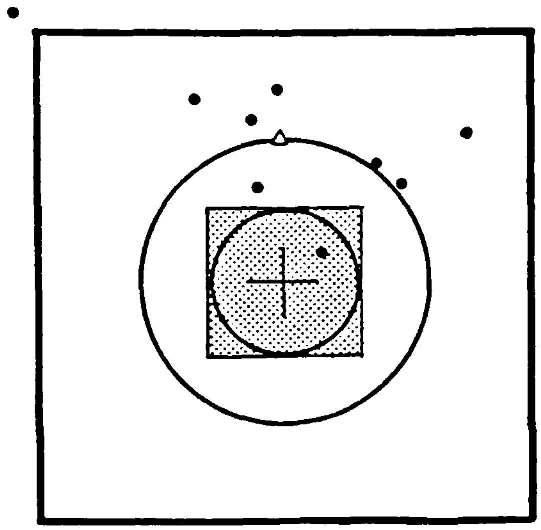
Even with inaccurate boresighting, results suggest that the 400-m offset zeroing procedure allowed effective sight alignment. While the first shot group was considerably more accurate for unscreened (Experiment 1) than screened (Experiment 2) boresight equipment, the accuracy of the second shot group was similar for both types of boresight equipment. Therefore, data suggest that the potential negative effects of inaccurate boresighting can be overcome by use of the 400-m offset zeroing procedure.

Zeroing Criterion

The zeroing criterion for the 25-mm gun requires that the strike of the round (for any ammunition) be observed within the 1-mil circle of the gun reticle (FM 23-1, 1983, 1987). Therefore, the point of impact can be no more than 0.5 mils from the aiming point of the sight. This level of accuracy is unrealistic based on dispersion characteristics of 25-mm ammunition. A previous mathematical analysis (Perkins, 1988a) indicated that when TP-T ammunition was manufactured to its maximum level of dispersion, then a circle with a 2-mil radius would be required to capture 90% of fired rounds.

To increase the level of accuracy when zeroing with TP-T ammunition, Perkins, 1988a, 1987) recommended the use of the center of a three-round shot group for sight alignment. Based on mathematical calculations, it was predicted that 90% of shot-group centers should fall within a 2-mil diameter circle (i.e., 1 mil from target center) (Perkins, 1987). Data from these experiments indicate that the proposed criterion can be achieved. After the first alignment of the sight, 12 of 13 (92%) of shot-group centers in Experiments 1 and 2 where within the 2-mil circle of the target. For shot-group centers in the 2-mil circle, only 33% (4 of 12) shot groups fell within 0.5 mils (a 1-mil circle) of target center. By contrast, twice as many shot group centers (8 of 12) fell from 0.5 to 1.0 mils from target center.

A. UNSCREENED BORESIGHT KITS



B. SCREENED BORESIGHT KITS

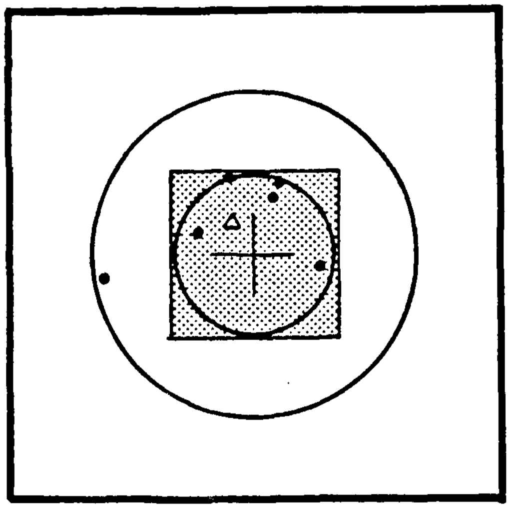


Figure 8. Shot-group centers after boresighting with: A. unscreened boresight kits and B. screened boresight kits. An 8-foot square boresight panel at 1200 m scaled relative to the 400-m target.

After the first sight alignment, only one shot-group center fell outside the 2-mil circle, and interestingly, this was the only vehicle that missed the 400-m target after boresighting. This latter case supports the contention that it is difficult to perform accurate reticle adjustments unless precise location of round impact can be obtained.

Accuracy at Near Recommended Zeroing Ranges

To be effective, the 400-m offset zeroing procedure should allow target hits at the recommended zeroing range of 1200 m, when the correct range control setting is used. Target placement on firing ranges did not have appropriate targets at that range so confirmation was performed at 1000 m. Four of the six vehicles during Experiment 2 had to fire on a 900-m target because of operational problems with the 1000 m target. When location of shot-group center was ballistically adjusted for the use of a range control setting of 1000 m on the 900 m target, data indicate that the shot-group center for all six vehicles was on or near target center of mass. Overall, results for both experiments suggest that the 400-m offset zeroing procedure when combined with three-round shot group procedures can produce a weapon zeroed at near recommended ranges.

Feedback

The capability to see holes in the 400-m target provided immediate feedback on round-impact location; this feedback does not occur at a range of 1200 m. Patching holes on a daily basis dramatically improved the gunner's ability to determine the hole created by the round. The capability to detect target holes was enhanced when the sky could be seen through the hole. Green trees and vegetation behind the hole made it more difficult to detect holes on the dark green target.

Score sheets provided another source of feedback. The use of score sheets allowed gunners to plot the perceived location of projectile impact, allowing confirmation by the other crew member and instructor. In general, there was much less disagreement on round-impact location at the 400-m target compared to the 1000-m target.

The potential problems of estimating round-impact location on a white target at 1000 m was best illustrated by a situation that developed in Experiment 1. The crew reported that rounds hit near the center of the target while the instructor on top of the vehicle insisted that rounds went over the target. One observer standing by the side of the vehicle was not really sure of impact location, but the best quess would have been under the target. Therefore, three people stated that rounds either hit the target, went over the target, or fell beneath the target. The data for this vehicle was not analyzed for obvious reasons.

Target Design

The design of the 400-m target is relatively simple. It has aiming points for the sight and gun, and circles that can be used to determine if a zeroing criterion is met. The 2-mil circle provides a criterion circle when using a three-round shot group with TP-T ammunition. The 4-mil circle was intended to provide additional target markings for plotting of round impact outside the 2-mil circle.

Zeroing in Combat

The design and measurement characteristics of the 400-m target were kept relatively simple for another critical reason, combat zeroing. Zeroing procedures as described in FM 23-1 are unrealistic in the combat environment. Big white targets will not exist and exact range will be difficult to estimate. Furthermore, it may not be feasible to zero at recommended ranges because of security problems associated with exposing a fighting position.

The current experiments suggest that the 400-m offset zeroing procedure is effective at near recommended zeroing ranges. After gunners understand the concept of short-range offset zeroing, it would be possible to conduct these procedures in a combat environment using field-expedient methods. All measurements used in construction of the target would be either 12 or 16 inches. A 16-inch string could be a standard component of the boresighting kit; and the string could be marked at 12 inches. The following is a potential field-expedient zeroing procedure.

A berm with a field of fire of approximately 400-m would be located or constructed. A rock about 4 inches in diameter would be placed in the center of the berm to serve as the center dot. The 16-inch string could be rotated around the center dot marking the 2-mil circle on either the ground or on a piece of cardboard using a marker. The reticle aiming cross (another rock) would be centered 16 inches to the left and 12 inches above the center dot. A 4-mil circle would not be required with AP ammunition.

The BFV could be positioned at or near 400 m by moving the vehicle until the outside of the 1-mil circle of the ISU was positioned with one edge on the 2-mil circle on the target and the opposite edge on the center dot. Mathematical calculations suggest that the zeroing criterion for AP ammunition should be 2-mils, using sight alignment changes based on firing of a single round. However, testing needs to determine whether a 1-mil (FM 23-1, 1987) or 2-mil (Perkins, 1987) circle is the optimal criterion for AP ammunition.

RECOMMENDATIONS

Recommendation 1. Conduct a feasibility experiment with 400-m offset zeroing procedure, followed by 1200 m confirmation, using one three-round shot group for each target.

This test would finalize the 400-m offset zeroing procedure before it is compared to alternative zeroing procedures. The results of Experiment 2 indicate that the 400-m offset zeroing target and procedures could zero the

25-mm gun at 1000 m. However, the inability to use the same confirmation target confounded the interpretation of the results. The recommended test would also eliminate the second shot group fired at the 400-m target as performed in Experiments 1 and 2.

Recommendation 2. Test the relative accuracy of the following alternative procedures: (1) 1200-m zeroing with sight alignment after each of three rounds, (2) 1200-m zeroing using a three-round shot group center for sight alignment, (3) 400-m offset zeroing using a three-round shot group center for sight alignment, and (4) 800-m zeroing using a three-round shot group center for sight alignment.

To the author's knowledge, alternative zeroing procedures for the 25-mm gun have not been compared in a test. The recommended test should be conducted with ranges and resources specifically scheduled for testing purposes only. Due to the extensive resource requirements, it would not be possible to conduct the test as part of a training environment. The major testing objective would be to determine the procedure that produces the most accurate zeroing with an allotment of 3 rounds of 25-mm TP-T ammunition for each vehicle. For the test, 3 rounds would be used to zero and another 3 rounds would be used to determine zeroing accuracy on a 1200-m target.

Alternative 1 represents the procedure presented in FM 23-1 while alternative 2 is identical to 1 except that sight alignment is based on the location of a shot-group center. Alternative 3 is the experimental procedure that should be refined after the completion of Recommendation 1. Alternative 4 represents an alternative to the recommended 1200-m zeroing range. Calculations based on gun-sight parallax indicate that the effects of zeroing at 800 m, 1000 m, and 1200 m are virtually identical when round-impact location is considered past the zeroing range. Use of the shorter range (i.e., 800 m) for zeroing should enhance target hit probability after boresighting, estimation of round-impact location, and reticle adjustment accuracy as compared to that obtained at 1200 m (see Perkins, 1987).

Recommendation 3. Develop field-expedient procedures for 400-m offset zeroing using AP ammunition and conduct a feasibility test.

Short-range offset zeroing procedures may be as critical in a combat environment as in training. Prior to positioning the vehicle in its defensive position, short-range zeroing could be performed in areas that are more secure without requiring the target ranges currently specified in FM 23-1. A possible target and zeroing scenario were presented in the Conclusion section.

Recommendation 4. Develop training package for short-range zeroing procedures for the BFV and incorporate into training.

The results of Recommendations 1, 2, and 3 will determine the assets and limitations of the short-range zeroing procedures. If gunnery effectiveness is enhanced by these procedures then training programs will require development and validation.

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APPENDIX A

EXPERIMENTAL 400M ZEROING PROCEDURE FOR EXPERIMENT 1

1. Set ISU:
   A. MAG to HIGH (12X).
   B. RANGE to 4 (400 m).
   C. Use gunner's control handles to position reticle center dot on Reticle Aiming Corner of target.

      NOTE: Do NOT traverse the turret or elevate-depress the gun unless instructed.

   D. Adjust RET BRIGHTNESS to dim level to lessen the "clutter" on the sight picture when firing.

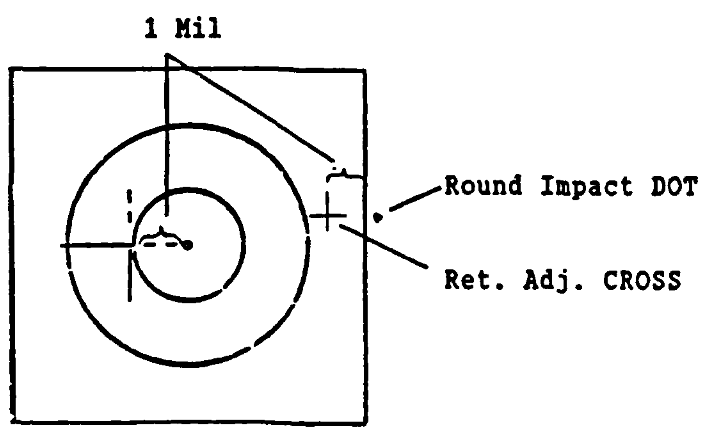
2. Set AMMO switches:
   A. SS mode.
   B. ARM-SAFE-RESET switch to ARM position.

3. Fire 1 round without squeezing the palm grips.

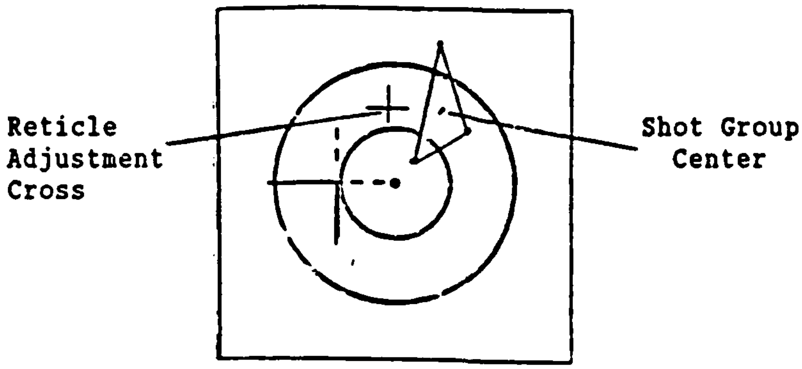
4. Mark a DOT on the Zeroing Sheet to record location of round impact.

5. The location of your first round will determine the next step. If the round:
   A. MISSES the target, go to Step 6 (1-shot adj. proc).
   B. HITS the target, go to Step 7 (3-shot adj. proc.).

6. Reticle adjustment based on firing of 1 round.
   A. Draw a CROSS 1 mil to the left of the dot used to show round location (See Figure below).
   B. Adjust Boresight Adjustment Knobs to position the reticle center on the CROSS.
   C. Relay the ISU reticle center on the Reticle Aiming Corner using the "G-pattern."
   D. Return to Step 3.



7. Reticle adjustment based on firing of 3 rounds.
   A. Fire 2 more rounds and use Zeroing Sheet to record round impact location.
   B. Connect the 3 dots showing shot group location
   C. Estimate and mark the center of the shot group.
   D. Mark a CROSS 1 mil to the left of the center of shot group.
   E. Relay the ISU reticle center on the Reticle Aiming Corner using the "G-pattern."



8. Repeat reticle adjustment using 3-round-*shot-group*.
   A. Fire 3 rounds plotting location on Zeroing Sheet after each round.
   B. Determine center of shot group.
   C. Mark a CROSS 1 mil to the left of the center of shot group.
   D. Relay the ISU reticle center on the Reticle Aiming Corner using the "G-pattern."

9. Set RANGE index to 10 (1000 m).

10. Use gunner's control handles to lay center dot of reticle on cross of the 1000 m boresighting panel.

11. Fire 3 rounds at the 1000 m target, recording round impact location on Zeroing Sheet.

APPENDIX B

EXPERIMENTAL ZEROING PROCEDURE FOR EXPERIMENT 2

1. Set ISU:
   A. MAG to HIGH (12X).
   B. RANGE to 4 (400 m).
   C. Use gunner's control handles to position reticle center dot on Reticle Aiming Cross of the 400-m zeroing target.

      NOTE: Do NOT traverse the turret or elevate-depress the gun unless instructed.

   D. Adjust RET BRIGHTNESS to dim level to lessen the "clutter" on the sight picture when firing.

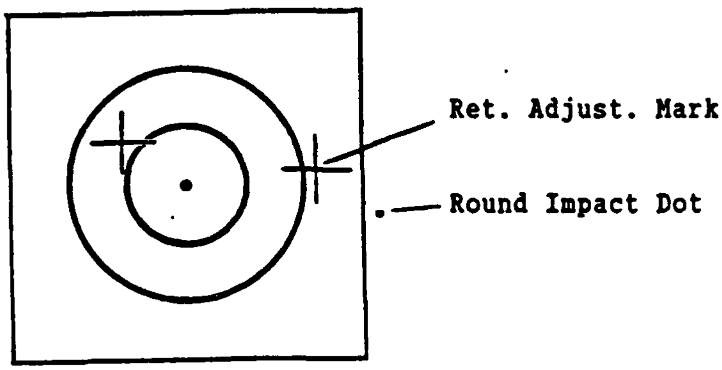
2. Set AMMO switches:
   A. SS mode.
   B. ARM-SAFE-RESET switch to ARM position.

3. Fire 1 round without squeezing the palm grips.

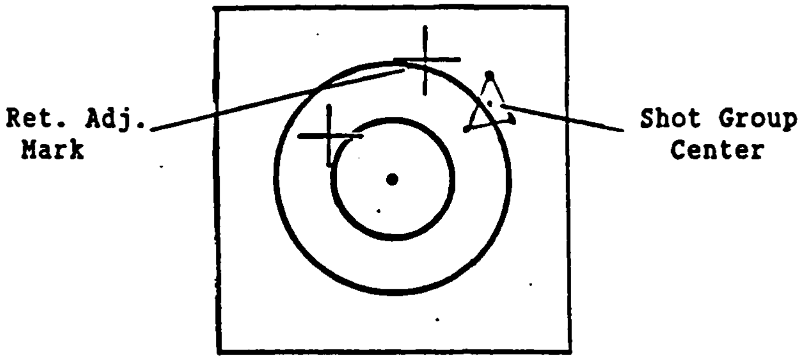
4. Mark a DOT on the Zeroing Sheet to record location of round impact.

5. The location of your first round will determine the next step. If the round:
   A. MISSES the target, go to Step 6 (1-shot adj. proc).
   B. HITS the target, go to Step 7 (3-shot adj. proc.).

6. Reticle adjustment based on firing of 1 round.
   A. Use Boresight Reticle Adjustment Overlay and the Zeroing Sheet to mark the position of reticle adjustment from round impact (See Figure below).
   B. Adjust reticle to Reticle Adjustment Mark using the Boresight Adjustment Knobs.
   C. Relay the ISU reticle center on the Reticle Aiming Cross using the "G-pattern."
   D. Return to Step 3.



7. Reticle adjustment based on firing of 3 rounds.
   A. Fire 2 more rounds and use Zeroing Sheet to record round impact location.
   B. Connect the 3 dots showing shot group location.
   C. Estimate and mark the center of the shot group.
   D. Use the Boresight Adjustment Overlay and the Zeroing Sheet to mark the position of reticle adjustment from round impact.
   E. Adjust reticle to Reticle Adjustment Mark using the Boresight Adjustment Knobs.
   F. Relay the ISU reticle center on the Reticle Aiming Corner using the "G-pattern."



8. Repeat reticle adjustment using 3-round-shot-group.
   A. Fire 3 rounds plotting location on Zeroing Sheet after each round.
   B. Determine center of shot group.
   C. Use Boresight Reticle Adjustment Overlay and Zeroing sheet to mark the position of reticle adjustment from round impact.
   D. Adjust reticle to Reticle Adjustment Mark using the Boresight Adjustment Knobs.
   E. Relay the ISU reticle center on the Reticle Aiming Cross using the "G-pattern."

9. Set RANGE index to 10 (1000 m).

10. Use gunner's control handles to lay center dot of reticle on cross of the 1000 m boresighting panel.

11. Fire 3 rounds at the 1000 m target, recording round impact location on Zeroing Sheet.

12. Mark shot group center on Zeroing Sheet and use Boresight Adjustment Knobs to adjust reticle to shot group center.